Exhibit F

Exhibit C-13

Invalidity of U.S. Patent No. 8,224,024 ("'024 Patent") under Pre-AIA Section 102 or Section 103 in view of Eric Foxlin, et al., "FlightTracker: A Novel Optical/Inertial Tracker for Cockpit Enhanced Vision," IEEE & ACM INT'L SYMP. ON MIXED AND AUGMENTED REALITY (ISMAR 2004) ("FlightTracker, Foxlin")[1]

FlightTracker, Foxlin was published in November 2004. Plaintiffs belatedly asserted a priority date of July 14, 2005 for the '024 Patent on December 22, 2021, 71 days after the Court's deadline. Defendants have reviewed Plaintiffs' alleged evidence of the purported July 14, 2005 priority date, and maintain that the '024 Patent is not entitled to this priority date. *See* Defendants' March 15, 2022 Supplemental Invalidity Contentions. Defendants reserve their objections to Plaintiffs' belated assertion of the new priority date and expressly reserve all rights to challenge this alleged new priority date. As such, Defendants assume for the sake of these invalidity contentions, that the priority date for the '024 Patent is October 4, 2005 based on the first filed Provisional Application from which the '024 Patent claims priority. (Defendants do not concede nor agree that Plaintiffs are even entitled to this date.) Assuming this priority date, FlightTracker, Foxlin qualifies as prior art under at least pre-AIA Section 102(a) to the '024 Patent.

As described herein, the asserted claims of the '024 Patent are invalid (a) under one or more sections of 35 U.S.C. § 102 as anticipated expressly or inherently by FlightTracker, Foxlin (including the documents incorporated into FlightTracker, Foxlin by reference) and (b) under 35 U.S.C. § 103 as obvious in view of FlightTracker, Foxlin standing alone and, additionally, in combination with the knowledge of one of ordinary skill in the art, and/or other prior art, including but not limited to the prior art identified in Defendants' Invalidity Contentions and the prior art described in the claim charts attached in Exhibits C-1 – C-25. With respect to the proposed modifications to FlightTracker, Foxlin, as of the priority date of the '024 Patent, such modification would have been obvious to try, an obvious combination of prior art elements according to known methods to yield predictable results, a simple substitution of one known element for another to obtain predictable results, a use of known techniques to improve a similar devices or method in the same way, an application of a known technique to a known device or method ready for improvement to yield predictable results, a variation of a known work in one field of endeavor for use in either the same field or a different one based on design incentives or other market forces with variations that are predictable to one of ordinary skill in the art, and/or obvious in view of teachings, suggestions, and motivations in the prior art that would have led one of ordinary skill to modify or combine the prior art references.

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[1] Discovery in this case is ongoing and, accordingly, this invalidity chart is not to be considered final. Defendants have conducted the invalidity analysis herein without having fully undergone claim construction and a *Markman* hearing. By charting the prior art against the claim(s) herein, Defendants are not admitting nor agreeing to Plaintiffs' interpretation of the claims at issue in this case. Additionally, these charts provide representative examples of portions of the charted references that disclose the indicated limitations under Plaintiffs' application of the claims; additional portions of these references other than the representative examples provided herein may also disclose the indicated limitation(s) and Defendants contend that the asserted claim(s) are invalid in light of the charted reference(s) as a whole. Defendants reserve the right to rely on additional citations or sources of evidence that also may be applicable, or that may become applicable in light of claim construction, changes in Plaintiffs' infringement contentions, and/or information obtained during discovery as the case progresses. Further, by submitting these invalidity contentions, Defendants do not waive and hereby expressly reserve their right to raise other invalidity defenses, including but not limited to defenses under Sections 101 and 112. Defendants reserve the right to amend or supplement this claim chart at a later date, including after the Court's order construing disputed claim terms.

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All cross-references should be understood to include material that is cross-referenced within the cross-reference. Where a particular figure is cited, the citation should be understood to encompass the caption and description of the figure as well as any text relating to or describing the figure. Conversely, where particular text referring to a figure is cited, the citation should be understood to include the figure as well.

A. Independent Claim 1

Claim 1	FlightTracker, Foxlin
[1.pre] A method comprising	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, a method comprising obtaining a camera image from a camera and processing said camera image in a data processor by computing the spatial location and azimuth of an object from the locations, in said camera image, of exactly two points on the object, and information about an orientation of the object, and generating one or more signals representative of the location and azimuth of the object. No party has yet asserted that the preamble is limiting, nor has the Court construed the preamble as limiting. However, to the extent that the preamble is limiting, it is disclosed by FlightTracker, Foxlin. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art. *See, e.g.*: One of the earliest fielded augmented reality applications was enhanced vision for pilots, in which a display projected on the pilot's visor provides geospatially registered information to help the pilot navigate, avoid obstacles, maintain situational awareness in reduced visibility, and interact with avionics instruments without looking down. This requires exceptionally robust and accurate head-tracking, for which there is not a sufficient solution yet available. In this paper, we apply miniature MEMS sensors to cockpit helmet-tracking for enhanced/synthetic vision by implementing algorithms for differential inertial tracking between helmet-mounted and aircraft-mounted inertial sensors, and novel optical drift correction techniques. By fusing low-rate inside-out and outside-in optical measurements with high-rate inertial data, we achieve millimeter position accuracy and milliradian angular accuracy, low-latency and high robustness using small and inexpensive sensors. FlightTracker, Foxlin at Abstract. **Various optical systems have been designed**, typically using video cameras or electro-optical position sensing devices mounted in the cockpit viewing several infrared LEDs on the helmet.

CLAIM 1	FlightTracker, Foxlin
	FlightTracker, Foxlin at 2. **[H]ead-trackers have been developed based on miniaturized inertial sensors [5, 6]. Inertial sensors have no range limitations, no line-of-sight requirements, and no risk of interference from any magnetic, acoustic, optical or RF interference sources.** They can be sampled as fast as desired, and provide relatively high-bandwidth motion measurement with negligible latency. Even tiny low-cost MEMS inertial sensors measure motion with very low noise resulting in jitter-free tracking which looks very smooth to the eye. Since they directly measure the motion derivatives, inertial trackers have the unique capability to perform high-quality prediction to compensate for graphics rendering and display rasterization latencies, without the noise problems of numerical differentiation. Unfortunately, any slight inertial sensor bias. FlightTracker, Foxlin at 2. Unfortunately, any slight inertial sensor bias or noise, when integrated over time, will cause the orientation and position outputs to gradually drift. With MEMS sensors suitable for helmet mounting, position drift is very fast, and even the orientation drift is problematic (tens or hundreds of degrees per hour). Thus, inertial sensors must be at least occasionally corrected by other sensors in a hybrid or aided-inertial tracking configuration. InterSense, has developed products which use tilt sensors and a compass to correct gyro drift in a sourceless orientation tracker (IS-300, introduced in 1996), followed by a hybrid tracking technology introduced in 1998 which fuses ultrasonic range measurements with inertial tracking for 6-DOF tracking applications. The newest version of this, called the IS-900 SimTracker, has rapidly become the most widely selected tracker for new simulator programs [7]. While the IS-900 SimTracker has proven the benefits of a drift-corrected inertial tracking solution for simulators, it is not directly suitable for use in cockpits. Firstly, the extremely high angular accuracy requirements call for an optical aiding technology instead of an acoustic one. Secondly, the inertial sensors measure motion relative to the ground, while the ultrasonic aiding sensors measure the position of the head-mounted microphones relative to the vehicle-mounted emitters. The Kalman filter expects both sets of measurements to be in the same coordinate frame, and would give erratic results if it were fed conflicting measurements. In this paper we report on the first prototype of the FlightTracker, which is designed to overcome these limitations. In Section 2 we present a condensed summary of the differential inertial tracking algorithms, originally derived in [8], which have been implemented in the FlightTracker to allow it to compensate for platform motion. In Section 3 we describe the novel inside-outside-in optical system employed by the FlightTracker to obtain the extremely high accuracy and robustness needed for the cockpit tracking application. Section 4 describes the prototype system

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CLAIM 1	FlightTracker, Foxlin
	implementation, and Section 5 shows preliminary test results which strongly suggest that the target accuracy and robustness goals will be easily exceeded by the final system. FlightTracker, Foxlin at 2. Most commercial optical trackers, including the current generation of optical helmet trackers, are outside-in, which means the optical sensors are fixed around the outside of the tracking volume looking inwards at optical targets mounted on the tracked objects. With 2-D sensors, a minimum of two outside-in sensors can be used to triangulate the position of a target, by essentially intersecting the rays from each camera towards the target. With 1-D optical sensors, a minimum of three sensors is needed to triangulate a target. Both methods are capable of triangulating the X,Y,Z location of a point target (such as an LED or a retro-reflective ball) to very high resolution and accuracy, typically better than 1 mm. However, for an outside-in tracker to obtain orientation, it must triangulate the positions of three point targets on the helmet, and solve for orientation from the positions. The quality of this orientation estimate is directly dependent on the quality of the position estimates and the separation between the point targets. With small separations between targets on a helmet, the orientation estimate is very sensitive to small errors in the position of any of the three targets. For example, with baseline separation of 100 mm, an error of 1 mm in one of the targets will cause an error of 10 mR in the orientation. **In 1990, the University of North Carolina – Chapel Hill reported an optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling.** This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras. Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive.

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CLAIM 1	FlightTracker, Foxlin
	Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three **optical tracking configurations** that can be created almost automatically using our flexible sensor fusion architecture [12]. Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker. This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (dotted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. Figure 7 shows an overview of the system that was used to collect the results in the next section. The key hardware component is the InertiaCam™ device originally developed for the VIS-Tracker product. The InertiaCam consists of a miniature sensor head and an image processing unit (IPU). The sensor head (26 x 15 x 49 mm) contains the inertial sensors, CCD and lens. The IPU contains a low-power DSP and interface electronics.

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CLAIM 1	FlightTracker, Foxlin
	For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out. FlightTracker, Foxlin at 7.

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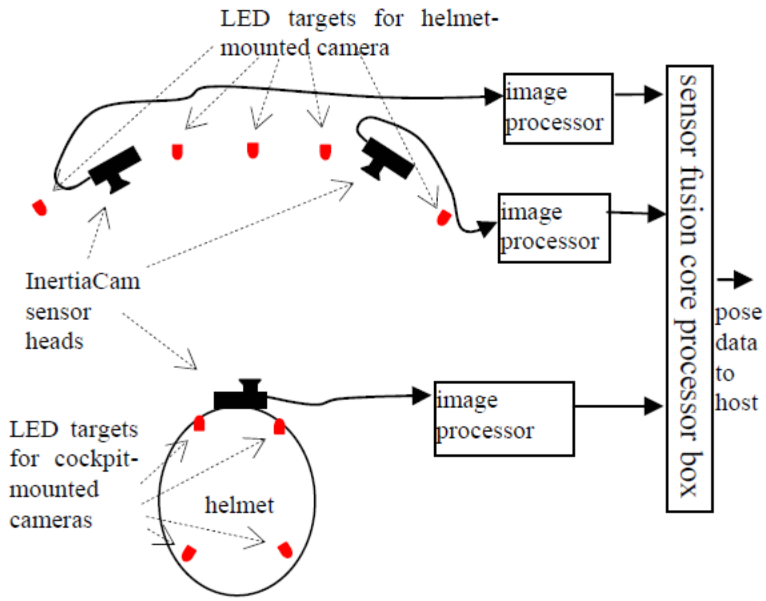
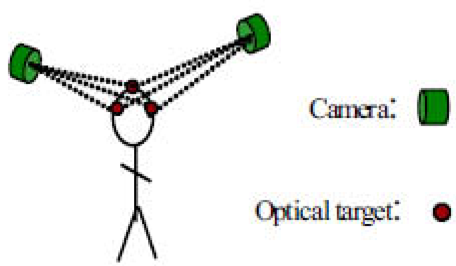
CLAIM 1	FlightTracker, Foxlin
	 **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.  **Figure 4: Outside-in optical tracking** FlightTracker, Foxlin at Fig. 4

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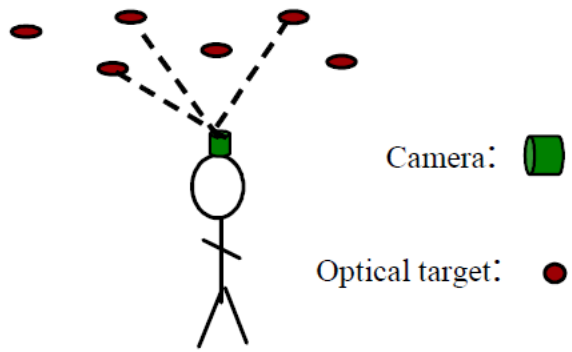
<table>
<tr><th>CLAIM 1</th><th>FlightTracker, Foxlin</th></tr>
<tr><td></td><td>


Figure 5: Inside-out optical tracking

FlightTracker, Foxlin at Fig. 5.

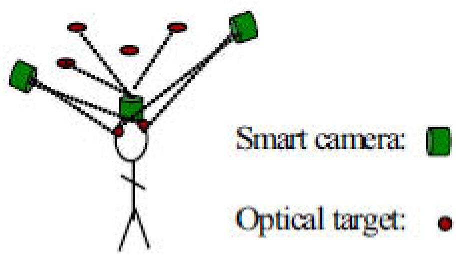


Figure 6: Inside-outside-in optical tracker.

FlightTracker, Foxlin at Fig. 6.

See also Defendants’ Invalidity Contentions for further discussion.
</td></tr>
<tr><td>[1.a] obtaining a camera image from a camera and processing said camera image in a data processor</td><td>
At least under Plaintiffs’ apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, obtaining a camera image from a camera and processing said camera image in a data processor. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants’ Invalidity Contentions and/or the knowledge of one of ordinary skill in the art.

See, e.g.:
</td></tr>
</table>

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CLAIM 1	FlightTracker, Foxlin
	One of the earliest fielded augmented reality applications was enhanced vision for pilots, in which a display projected on the pilot's visor provides geospatially registered information to help the pilot navigate, avoid obstacles, maintain situational awareness in reduced visibility, and interact with avionics instruments without looking down. This requires exceptionally robust and accurate head-tracking, for which there is not a sufficient solution yet available. In this paper, we apply miniature MEMS sensors to cockpit helmet-tracking for enhanced/synthetic vision by implementing algorithms for differential inertial tracking between helmet-mounted and aircraft-mounted inertial sensors, and novel optical drift correction techniques. By fusing low-rate inside-out and outside-in optical measurements with high-rate inertial data, we achieve millimeter position accuracy and milliradian angular accuracy, low-latency and high robustness using small and inexpensive sensors. FlightTracker, Foxlin at Abstract. **In synthetic vision, the head-tracker is used to slave externally mounted sensors (visible, IR, radar, etc.) that are fused with one another and possibly also with a computer terrain model, to produce a visual display that replaces the pilot's natural vision**. Therefore, a slightly lower accuracy might be acceptable as long as the tracker meets the resolution and responsiveness requirements of a virtual reality HMD system. FlightTracker, Foxlin at 1. Figure 1 illustrates the simple case of using an inertial system to track the pose of a body, b, with respect to a fixed navigation frame, n. In this situation, which accurately represents the operation of current inertial tracking products, there are only two coordinate frames used. Vectors and matrices are designated with boldface characters, and superscripts, if present, indicate in which frame vectors are coordinatized. The subscripts on **r**nb indicate that it is the position displacement vector from the n-frame origin to the b-frame origin. Likewise, $\boldsymbol{\omega}_{nb}^{b}$ represents the angular rate vector of the b-frame w.r.t. the n-frame coordinatized in the b-frame. This is exactly what the strapped-down triad of rate gyros aligned with the b-frame axes measures. The accelerometer triad at the b-frame origin senses $\mathbf{f}_{nb}^{b}$, the non-gravitational acceleration (a.k.a. specific **f**orce) of b-frame w.r.t. the inertial reference frame, n , expressed in b-frame. The orientation of the b-frame w.r.t. the n-frame can be represented using a 3x3 rotation matrix $\mathbf{C}_{b}^{n}$ that transforms vectors from b-frame to n-frame: $\mathbf{v}^{n} = \mathbf{C}_{b}^{n}\mathbf{v}^{b}$. The orientation is integrated using the continuous-time (CT) differential equation $\dot{\mathbf{C}}_{b}^{n} = \mathbf{C}_{b}^{n} S(\boldsymbol{\omega}_{nb}^{b})$, where $S(\boldsymbol{\omega}_{nb}^{b}) \equiv [\boldsymbol{\omega}_{nb}^{b} \times]$ is the skew-symmetric matrix formed from the elements of ω_{nb}^{b} to implement the cross-product operator noted in the square brackets. The

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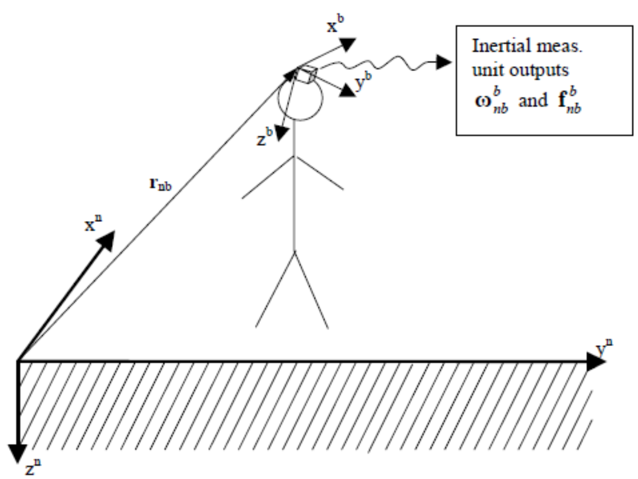
CLAIM 1	FlightTracker, Foxlin
	updated rotation matrix is then used to resolve the accelerometer readings into the n-frame, whence they can be easily corrected for the effect of gravity and double integrated to obtain the head position using: $\dot{\mathbf{v}}_{nb}^{n} = \mathbf{C}_{b}^{n}\mathbf{f}_{nb}^{b} + \mathbf{g}^{n}$ $\dot{\mathbf{r}}_{nb}^{n} = \mathbf{v}_{nb}^{n}$ where $\mathbf{g}^{n} \approx \begin{bmatrix} 0 & 0 & 9.8m/s^{2} \end{bmatrix}^{T}$ is the local apparent gravity vector which by definition points downward in n-frame. Equations (1) and (2) are integrated numerically to keep track of orientation, velocity and position. They are simplified compared to those used in terrestrial inertial navigation, but the gyro sensors in the InertiaCube™ are not sensitive enough to detect the 15°/hr rotation of the earth, so there is no need to include terms to compensate for its effect on the sensors. The drift that results from using such low-performance gyros and neglecting the effects of earth rotation must be frequently corrected by other means, such as ultrasonic or optical measurements. FlightTracker, Foxlin at 3. **2.1. Inertial tracking relative to fixed platform**  **Figure 1: Inertial Tracking Relative to Stationary Ground** FlightTracker, Foxlin at 3.

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	With 2-D sensors, a minimum of two outside-in sensors can be used to triangulate the position of a target, by essentially intersecting the rays from each camera towards the target. With 1-D optical sensors, a minimum of three sensors is needed to triangulate a target. Both methods are capable of triangulating the X,Y,Z location of a point target (such as an LED or a retro-reflective ball) to very high resolution and accuracy, typically better than 1 mm. However, for an outside-in tracker to obtain orientation, it must triangulate the positions of three point targets on the helmet, and solve for orientation from the positions. The quality of this orientation estimate is directly dependent on the quality of the position estimates and the separation between the point targets. With small separations between targets on a helmet, the orientation estimate is very sensitive to small errors in the position of any of the three targets. For example, with baseline separation of 100 mm, an error of 1 mm in one of the targets will cause an error of 10 mR in the orientation. FlightTracker, Foxlin at 5 In 1990, the University of North Carolina – Chapel Hill reported an optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. This was accomplished by the use of "inside-out" optical tracking, in which **the cameras are placed on the user's head** and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras. Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive. Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product.

CLAIM 1	FlightTracker, Foxlin
	FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. **Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker.** This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. **To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°.** Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. The "inside-outside-in" configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. **The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm.** Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with fewer targets or sensors. **Orientation tracking is left to the single head-mounted sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian.** FlightTracker, Foxlin at 6

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	The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy **if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet.** Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom. FlightTracker, Foxlin at 6. Figure 7 shows an overview of the system that was used to collect the results in the next section. The key hardware component is the InertiaCam™ device originally developed for the VIS-Tracker product. The InertiaCam consists of a miniature sensor head and an image processing unit (IPU). The sensor head (26 x 15 x 49 mm) contains the inertial sensors, CCD and lens. The IPU contains a low-power DSP and interface electronics. For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. **We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials.** To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. **We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition**. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. **The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out.** FlightTracker, Foxlin at 7. We developed an augmented reality (AR) program to demonstrate the registration accuracy of the tracking system. **This program receives video frames from a firewire camera**, applies them as a background texture map in OpenGL, and then renders foreground objects according to the camera viewpoint as reported by the motion tracking system. The geometry of the foreground "augmentations" are determined by creating a 3D model in 3DStudio and exporting a file in .3ds format. This file is loaded by the AR demo program and rendered at 60

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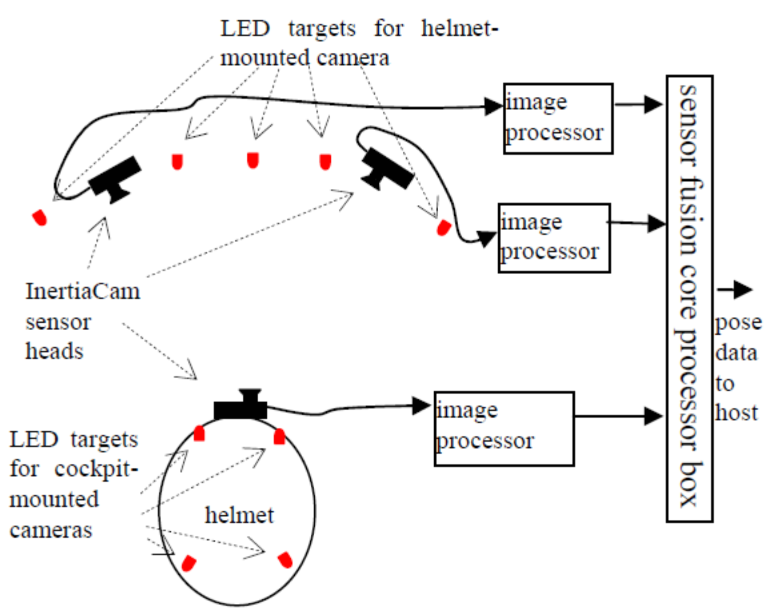
CLAIM 1	FlightTracker, Foxlin
	frames per second from the dynamically changing viewpoint received from the tracker. The result is a window showing the video from the firewire camera, augmented with virtual objects which appear to be superimposed on top of corresponding real objects. For the demo, we created a 3D model of the "canopy bow", with a photograph of cockpit instrumentation added in the interior space, which was superimposed on top of the real black metal "canopy bow". The registration appeared very good, on the order of 1-3 mm apparent displacement. There was almost no perceptible lag or dynamic misregistration. We recorded video of the AR overlay demo, which gives a good subjective impression of the registration accuracy both static and dynamic. However, we have yet to find a good way to quantify this registration accuracy. From the video, we know that the errors appear to be unbiased- the overlay is sometimes shifted a little left, sometimes a little right, but on average it is right on top of the real object. For now we are using just stability, jitter and repeatability measurements to characterize the tracking system. FlightTracker, Foxlin at 8.  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.

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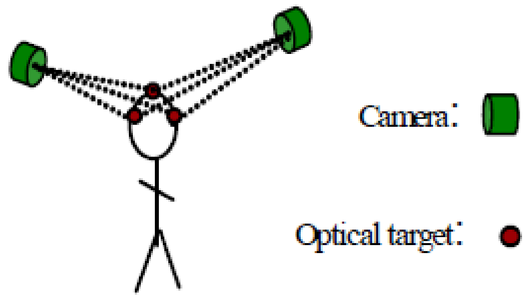
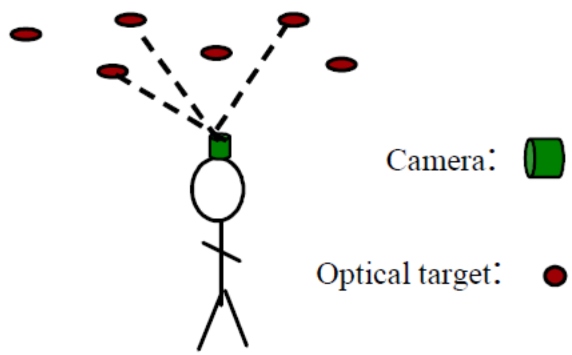
CLAIM 1	FlightTracker, Foxlin
	 Figure 4: Outside-in optical tracking FlightTracker, Foxlin at Fig. 4  Figure 5: Inside-out optical tracking FlightTracker, Foxlin at Fig. 5.

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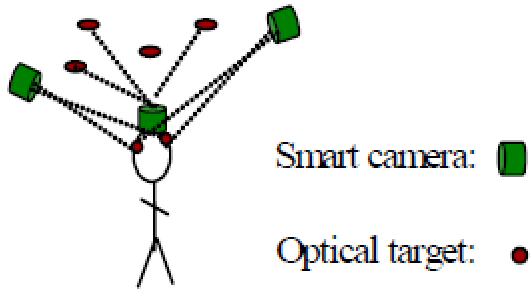
CLAIM 1	FlightTracker, Foxlin
	 Figure 6: Inside-outside-in optical tracker. FlightTracker, Foxlin at Fig. 6 *See also* Defendants' Invalidity Contentions for further discussion.
[1.b] by computing the spatial location and azimuth of an object from the locations, in said camera image, of exactly two points on the object, and information about an orientation of the object, and	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, by computing the spatial location and azimuth of an object from the locations, in said camera image, of exactly two points on the object, and information about an orientation of the object. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art. *See, e.g.*: In synthetic vision, **the head-tracker is used to slave externally mounted sensors (visible, IR, radar, etc.) that are fused with one another and possibly also with a computer terrain model, to produce a visual display that replaces the pilot's natural vision**. Therefore, a slightly lower accuracy might be acceptable as long as the tracker meets the resolution and responsiveness requirements of a virtual reality HMD system. FlightTracker, Foxlin at 1. Figure 1 illustrates the simple case of using an inertial system to track the pose of a body, b, with respect to a fixed navigation frame, n. **In this situation, which accurately represents the operation of current inertial tracking products, there are only two coordinate frames used**. Vectors and matrices are designated with boldface characters, and superscripts, if present, indicate in which frame vectors are coordinatized. The subscripts on **r**nb indicate that it is the position displacement vector from the n-frame origin to the b-frame origin. Likewise, $\boldsymbol{\omega}^{b}_{nb}$

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CLAIM 1	FlightTracker, Foxlin
	represents the angular rate vector of the b-frame w.r.t. the n-frame coordinatized in the b-frame. This is exactly what the strapped-down triad of rate gyros aligned with the b-frame axes measures. The accelerometer triad at the b-frame origin senses $\mathbf{f}_{nb}^{b}$, the non-gravitational acceleration (a.k.a. specific force) of b-frame w.r.t. the inertial reference frame, n , expressed in b-frame. The orientation of the b-frame w.r.t. the n-frame can be represented using a 3x3 rotation matrix $\mathbf{C}_b^n$ that transforms vectors from b-frame to n-frame: $\mathbf{v}^n = \mathbf{C}_b^n \mathbf{v}^b$. The orientation is integrated using the continuous-time (CT) differential equation $\dot{\mathbf{C}}_b^n = \mathbf{C}_b^n S(\boldsymbol{\omega}_{nb}^b)$, where $S(\boldsymbol{\omega}_{nb}^b) \equiv [\boldsymbol{\omega}_{nb}^b \times]$ is the skew-symmetric matrix formed from the elements of ω_{nb}^b to implement the cross-product operator noted in the square brackets. The updated rotation matrix is then used to resolve the accelerometer readings into the n-frame, whence they can be easily corrected for the effect of gravity and double integrated to obtain the head position using: $$\dot{\mathbf{v}}_{nb}^n = \mathbf{C}_b^n \mathbf{f}_{nb}^b + \mathbf{g}^n$$ $$\dot{\mathbf{r}}_{nb}^n = \mathbf{v}_{nb}^n$$ where $\mathbf{g}^n \approx [0 \quad 0 \quad 9.8m/s^2]^T$ is the local apparent gravity vector which by definition points downward in n-frame. Equations (1) and (2) are integrated numerically to keep track of orientation, velocity and position. **They are simplified compared to those used in terrestrial inertial navigation, but the gyro sensors in the InertiaCube™ are not sensitive enough to detect the 15°/hr rotation of the earth, so there is no need to include terms to compensate for its effect on the sensors. The drift that results from using such low-performance gyros and neglecting the effects of earth rotation must be frequently corrected by other means, such as ultrasonic or optical measurements.** FlightTracker, Foxlin at 3.

Exhibit C-13

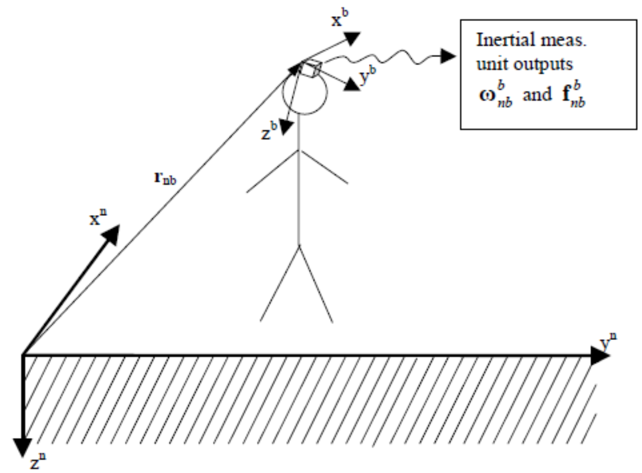
CLAIM 1	FlightTracker, Foxlin
	2.1. Inertial tracking relative to fixed platform  **Figure 1: Inertial Tracking Relative to Stationary Ground** FlightTracker, Foxlin at 3. In 1990, the University of North Carolina – Chapel Hill reported **an optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras**. Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive.

Exhibit C-13

CLAIM 1	FlightTracker, Foxlin
	Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker. This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. **The "inside-outside-in" configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm. Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with fewer targets or sensors. Orientation tracking is left to the single head-mounted**

Exhibit C-13

CLAIM 1	FlightTracker, Foxlin
	sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian. FlightTracker, Foxlin at 6 **The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6. The drawing shows two outside-in cameras, as this is enough to completely constrain the head position without any use of the inside-out camera. In concert with the inside-out camera, even one outside-in camera would be sufficient to lock up all DOFs except for translation along the outside camera's axis. Thus two outside cameras is already highly redundant, allowing great robustness for occlusions. FlightTracker, Foxlin at 6. A simulation was provided showing the improvement in an AR scenario in which pose data from an outside-in optical tracker (Northern Digital Optotrak) was combined with pose data obtained by solving a pose recovery algorithm from an inside-out camera viewing 5 LED targets. **This method works by first computing the 6-DOF pose from the outside-in tracker and the 6-DOF pose from the inside-out tracker and then fusing the two 6-DOF pose estimates**. While this suffices to demonstrate the accuracy improvement that can be obtained by the inside-outside-in method, it does not reap the full benefit in robustness that can be obtained, since both trackers must see enough targets to provide 6-DOF pose estimates. **In our implementation, the system will automatically fuse any 2-D bearing measurements obtained from any of the outside-in cameras and any inside-out 2-D bearing measurements with the pose being maintained by the inertial sensors, using a real-time Extended Kalman Filter. Therefore, it is not necessary for the inside-out camera to see a complete set of targets in order to provide useful data, nor is it necessary for any head-mounted target to be seen by more than one outside-in camera in order for its measurement to be used. We can block all the inside-out targets, or all the outside-in targets, or most of both sets of targets, and only slightly affect the tracking quality.** FlightTracker, Foxlin at 6-7

Exhibit C-13

CLAIM 1	FlightTracker, Foxlin
	For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. **We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition.** The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. **During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out.** FlightTracker, Foxlin at 7. During operation in the aircraft, the system starts out in acquisition mode, and then switches to tracking mode as soon as it is able to acquire an initial pose estimate. In the unlikely event that the tracking gets lost (e.g. the helmet is removed from the tracking area for an extended time), the system will automatically return to acquisition mode and re-acquire, typically in less than a second. During acquisition, the SFC scheduler requests each sensor to perform a "scan" and report all targets it can see and decode. The sensor/target measurement results are stacked in an accumulator, and if there is a sufficient combination the system solves for pose, otherwise it restarts the scan. FlightTracker, Foxlin at 7. During tracking mode, the system performs one scheduling operation, one inertial update and Kalman propagation step, and one Kalman measurement update (if there is a new measurement return available) on each cycle, running at 180 cycles/second. Because of the total generality of the SFC architecture, the scheduler is actually the most complex and computationally intensive part. For each sensor, the system finds all potential targets which are currently within its field-of-view and oriented so as to be usable. The list of all potential sensor-target pairs is submitted to an arbitration server to coordinate use of shared sensor/target resources between multiple SFCs on the same system or operating in the same area.

Exhibit C-13

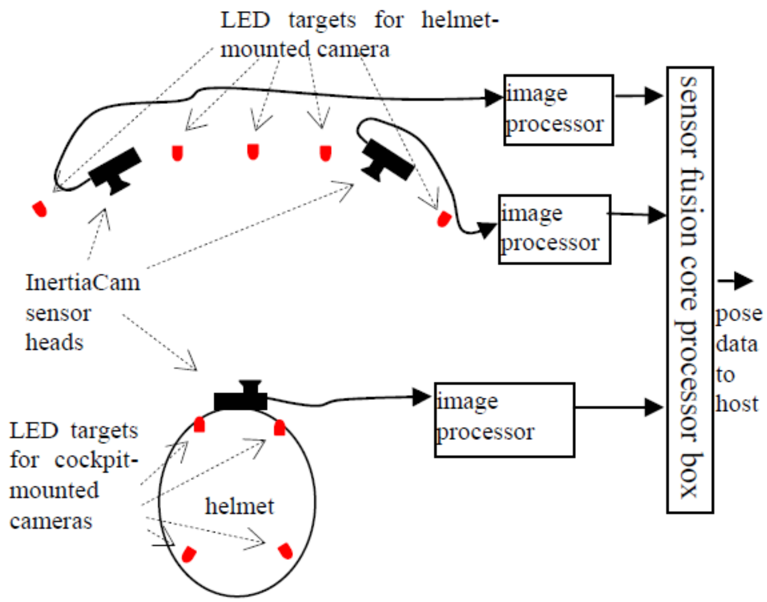
CLAIM 1	FlightTracker, Foxlin
	FlightTracker, Foxlin at 8.  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.

Exhibit C-13

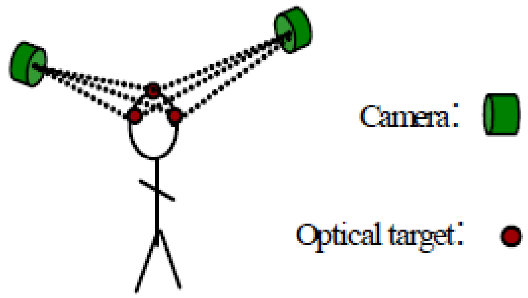
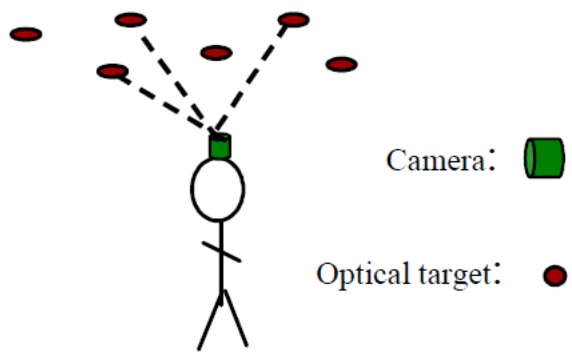
CLAIM 1	FlightTracker, Foxlin
	 Figure 4: Outside-in optical tracking FlightTracker, Foxlin at Fig. 4  Figure 5: Inside-out optical tracking FlightTracker, Foxlin at Fig. 5.

Exhibit C-13

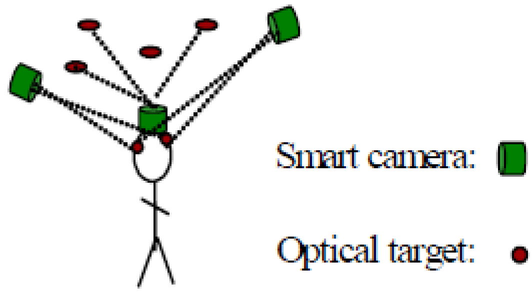
<table>
<tr><th>CLAIM 1</th><th>FlightTracker, Foxlin</th></tr>
<tr><td></td><td>

Figure 6: Inside-outside-in optical tracker.
FlightTracker, Foxlin at Fig. 6

See also Defendants' Invalidity Contentions for further discussion.</td></tr>
<tr><td>[1.c] generating one or more signals representative of the location and azimuth of the object, wherein computing the azimuth of the object comprises:</td><td>At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, generating one or more signals representative of the location and azimuth of the object. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art.

See, e.g.:

In synthetic vision, the head-tracker is used to slave externally mounted sensors (visible, IR, radar, etc.) that are fused with one another and possibly also with a computer terrain model, to produce a visual display that replaces the pilot's natural vision. Therefore, a slightly lower accuracy might be acceptable as long as the tracker meets the resolution and responsiveness requirements of a virtual reality HMD system.
FlightTracker, Foxlin at 1.

In this section, we develop the equations to compute the changes in orientation and position of a pilot's helmet relative to the aircraft by combining inertial data from a helmet-mounted tracking IMU and an aircraft-mounted reference IMU. This produces a differential inertial measurement of the head motion relative to the aircraft, which can then have its drift corrected by periodic optical measurements of the head position relative to the aircraft, using a very similar Kalman filter error estimator to that which was used in the IS-600 and IS-900 for tracking a head relative to the earth with a single inertial sensor corrected by earth-relative aiding sensors. We start by outlining ordinary inertial tracking relative to the earth to familiarize</td></tr>
</table>

Exhibit C-13

CLAIM 1	FlightTracker, Foxlin
	the reader with our notation and basic inertial tracking concepts, and then develop the more complex equations for tracking relative to a moving platform. FlightTracker, Foxlin at 3. Figure 1 illustrates the simple case of using an inertial system to track the pose of a body, b, with respect to a fixed navigation frame, n. In this situation, which accurately represents the operation of current inertial tracking products, there are only two coordinate frames used. Vectors and matrices are designated with boldface characters, and superscripts, if present, indicate in which frame vectors are coordinatized. The subscripts on **r**nb indicate that it is the position displacement vector from the n-frame origin to the b-frame origin. Likewise, $\boldsymbol{\omega}_{nb}^{b}$ represents the angular rate vector of the b-frame w.r.t. the n-frame coordinatized in the b-frame. This is exactly what the strapped-down triad of rate gyros aligned with the b-frame axes measures. The accelerometer triad at the b-frame origin senses $\mathbf{f}_{nb}^{b}$, the non-gravitational acceleration (a.k.a. specific **f**orce) of b-frame w.r.t. the inertial reference frame, n , expressed in b-frame. The orientation of the b-frame w.r.t. the n-frame can be represented using a 3x3 rotation matrix $\mathbf{C}_b^n$ that transforms vectors from b-frame to n-frame: $\mathbf{v}^n = \mathbf{C}_b^n \mathbf{v}^b$. The orientation is integrated using the continuous-time (CT) differential equation $\dot{\mathbf{C}}_b^n = \mathbf{C}_b^n S(\boldsymbol{\omega}_{nb}^b)$, where $S(\boldsymbol{\omega}_{nb}^b) \equiv [\boldsymbol{\omega}_{nb}^b \times]$ is the skew-symmetric matrix formed from the elements of ω_{nb}^b to implement the cross-product operator noted in the square brackets. The updated rotation matrix is then used to resolve the accelerometer readings into the n-frame, whence they can be easily corrected for the effect of gravity and double integrated to obtain the head position using: $$\dot{\mathbf{v}}_{nb}^n = \mathbf{C}_b^n \mathbf{f}_{nb}^b + \mathbf{g}^n$$ $$\dot{\mathbf{r}}_{nb}^n = \mathbf{v}_{nb}^n$$ where $\mathbf{g}^n \approx \begin{bmatrix} 0 & 0 & 9.8m/s^2 \end{bmatrix}^T$ is the local apparent gravity vector which by definition points downward in n-frame. Equations (1) and (2) are integrated numerically to keep track of orientation, velocity and position. They are simplified compared to those used in terrestrial inertial navigation, but the gyro sensors in the InertiaCube™ are not sensitive enough to detect the 15°/hr rotation of the earth, so there is no need to include terms to compensate for its effect on the sensors. The drift that results from using such low-performance gyros and neglecting the effects of earth rotation must be frequently corrected by other means, such as ultrasonic or optical measurements. FlightTracker, Foxlin at 3.

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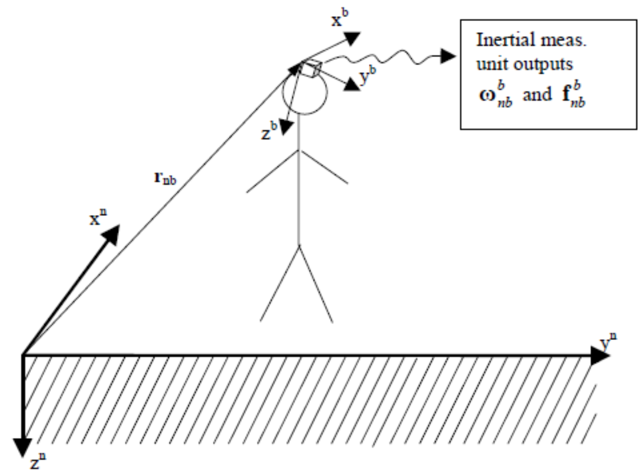
	2.1. Inertial tracking relative to fixed platform  **Figure 1: Inertial Tracking Relative to Stationary Ground** FlightTracker, Foxlin at 3. In 1990, the University of North Carolina – Chapel Hill reported **an optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras.** Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive.

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	offers extremely high angular resolution even with a modest resolution sensor. **With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian.** FlightTracker, Foxlin at 6 The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. **Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6. The drawing shows two outside-in cameras, as this is enough to completely constrain the head position without any use of the inside-out camera. In concert with the inside-out camera, even one outside-in camera would be sufficient to lock up all DOFs except for translation along the outside camera's axis. Thus two outside cameras is already highly redundant, allowing great robustness for occlusions. FlightTracker, Foxlin at 6. For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. **To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions**. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out.

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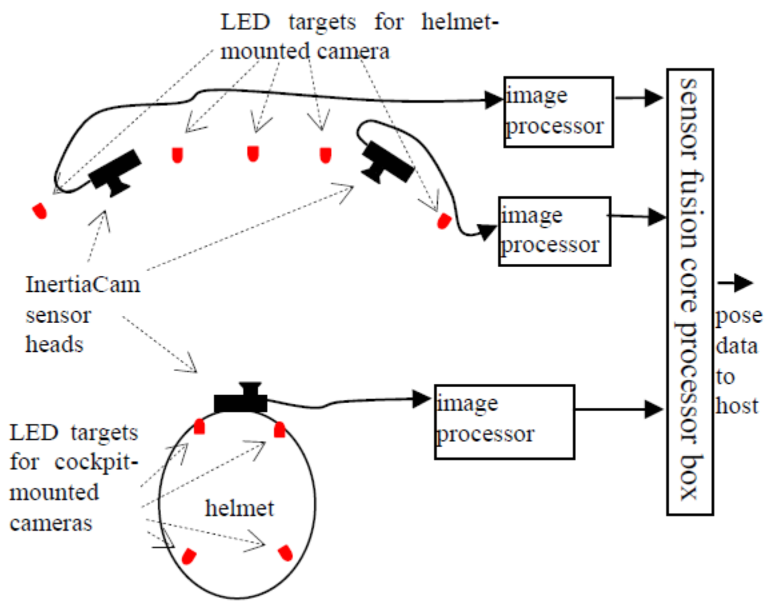
	FlightTracker, Foxlin at 7. During operation in the aircraft, the system starts out in acquisition mode, and then switches to tracking mode as soon as it is able to acquire an initial pose estimate. In the unlikely event that the tracking gets lost (e.g. the helmet is removed from the tracking area for an extended time), the system will automatically return to acquisition mode and re-acquire, typically in less than a second. During acquisition, the SFC scheduler requests each sensor to perform a "scan" and report all targets it can see and decode. The sensor/target measurement results are stacked in an accumulator, and if there is a sufficient combination the system solves for pose, otherwise it restarts the scan. FlightTracker, Foxlin at 7.  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.

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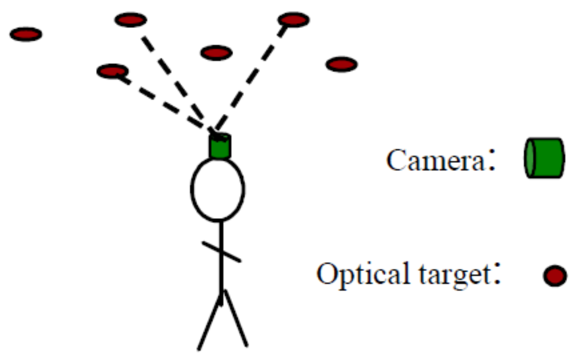
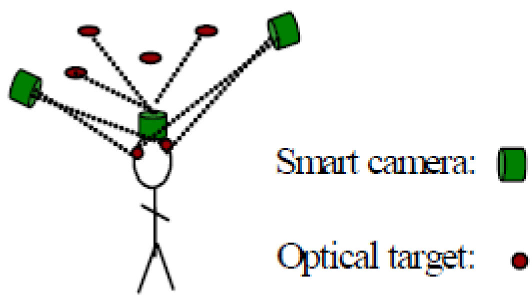
	 **Figure 5: Inside-out optical tracking** FlightTracker, Foxlin at Fig. 5.  **Figure 6: Inside-outside-in optical tracker.** FlightTracker, Foxlin at Fig. 6 *See also* Defendants' Invalidity Contentions for further discussion.
[1.d] receiving coordinate information for images, on an imaging device of a camera, of two points on an object,	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, receiving coordinate information for images, on an imaging device of a camera, of two points on an object. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art. *See, e.g.*:

CLAIM 1	FlightTracker, Foxlin
	In synthetic vision, the head-tracker is used to slave externally mounted sensors (visible, IR, radar, etc.) that are fused with one another and possibly also with a computer terrain model, to produce a visual display that replaces the pilot's natural vision. Therefore, a slightly lower accuracy might be acceptable as long as the tracker meets the resolution and responsiveness requirements of a virtual reality HMD system. FlightTracker, Foxlin at 1. Figure 1 illustrates the simple case of using an inertial system to track the pose of a body, b, with respect to a fixed navigation frame, n. In this situation, which accurately represents the operation of current inertial tracking products, there are only two coordinate frames used. Vectors and matrices are designated with boldface characters, and superscripts, if present, indicate in which frame vectors are coordinatized. The subscripts on **r**nb indicate that it is the position displacement vector from the n-frame origin to the b-frame origin. Likewise, $\boldsymbol{\omega}_{nb}^{b}$ represents the angular rate vector of the b-frame w.r.t. the n-frame coordinatized in the b-frame. This is exactly what the strapped-down triad of rate gyros aligned with the b-frame axes measures. The accelerometer triad at the b-frame origin senses $\mathbf{f}_{nb}^{b}$, the non-gravitational acceleration (a.k.a. specific **f**orce) of b-frame w.r.t. the inertial reference frame, n , expressed in b-frame. The orientation of the b-frame w.r.t. the n-frame can be represented using a 3x3 rotation matrix $\mathbf{C}_{b}^{n}$ that transforms vectors from b-frame to n-frame: $\mathbf{v}^{n} = \mathbf{C}_{b}^{n}\mathbf{v}^{b}$. The orientation is integrated using the continuous-time (CT) differential equation $\dot{\mathbf{C}}_{b}^{n} = \mathbf{C}_{b}^{n} S(\boldsymbol{\omega}_{nb}^{b})$, where $S(\boldsymbol{\omega}_{nb}^{b}) \equiv [\boldsymbol{\omega}_{nb}^{b} \times]$ is the skew-symmetric matrix formed from the elements of ω_{nb}^{b} to implement the cross-product operator noted in the square brackets. The updated rotation matrix is then used to resolve the accelerometer readings into the n-frame, whence they can be easily corrected for the effect of gravity and double integrated to obtain the head position using: $$\dot{\mathbf{v}}_{nb}^{n} = \mathbf{C}_{b}^{n}\mathbf{f}_{nb}^{b} + \mathbf{g}^{n}$$ $$\dot{\mathbf{r}}_{nb}^{n} = \mathbf{v}_{nb}^{n}$$ where $\mathbf{g}^{n} \approx \begin{bmatrix} 0 & 0 & 9.8m/s^{2} \end{bmatrix}^{T}$ is the local apparent gravity vector which by definition points downward in n-frame. Equations (1) and (2) are integrated numerically to keep track of orientation, velocity and position. They are simplified compared to those used in terrestrial inertial navigation, but the gyro sensors in the InertiaCube™ are not sensitive enough to detect the 15°/hr rotation of the earth, so there is no need to include terms to compensate for its effect on the sensors. The drift that results from using such low-performance gyros and neglecting the effects of earth rotation must be frequently corrected by other means, such as ultrasonic or optical measurements. FlightTracker, Foxlin at 3.

Exhibit C-13

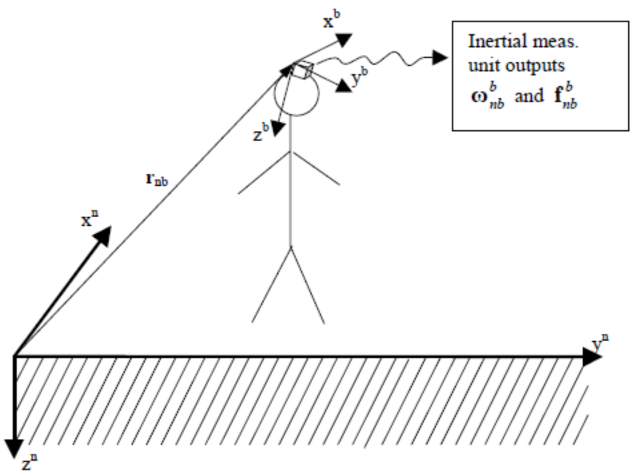
CLAIM 1	FlightTracker, Foxlin
	2.1. Inertial tracking relative to fixed platform  **Figure 1: Inertial Tracking Relative to Stationary Ground** FlightTracker, Foxlin at 3. In 1990, the University of North Carolina – Chapel Hill reported an **optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras.** Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive.

Exhibit C-13

CLAIM 1	FlightTracker, Foxlin
	Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, **InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance** [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. **Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker.** This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. **The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination.** FlightTracker, Foxlin at 5-6. The "inside-outside-in" configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm. Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with

CLAIM 1	FlightTracker, Foxlin
	fewer targets or sensors. Orientation tracking is left to the single head-mounted sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian. FlightTracker, Foxlin at 6 **The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6. Figure 7 shows an overview of the system that was used to collect the results in the next section. **The key hardware component is the InertiaCam™ device originally developed for the VIS-Tracker product. The InertiaCam consists of a miniature sensor head and an image processing unit (IPU). The sensor head (26 x 15 x 49 mm) contains the inertial sensors, CCD and lens. The IPU contains a low-power DSP and interface electronics.** For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. W**e have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition.** The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. **During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and**

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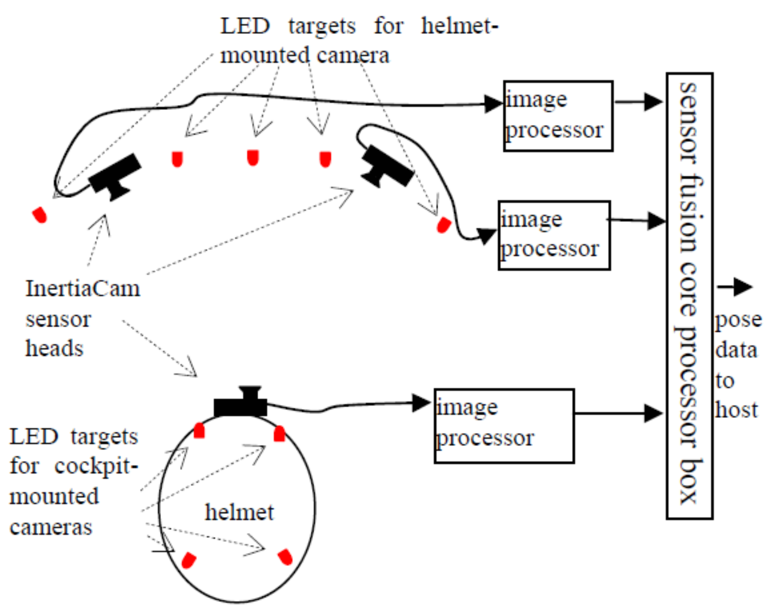
CLAIM 1	FlightTracker, Foxlin
	which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out. FlightTracker, Foxlin at 7. During operation in the aircraft, the system starts out in acquisition mode, and then switches to tracking mode as soon as it is able to acquire an initial pose estimate. In the unlikely event that the tracking gets lost (e.g. the helmet is removed from the tracking area for an extended time), the system will automatically return to acquisition mode and re-acquire, typically in less than a second. During acquisition, the SFC scheduler requests each sensor to perform a "scan" and report all targets it can see and decode. The sensor/target measurement results are stacked in an accumulator, and if there is a sufficient combination the system solves for pose, otherwise it restarts the scan. Minimum sufficient combinations are either 4 inside-out measurements (not all 4 targets collinear), 4 outside-in (at least 3 targets, not all collinear), 1 outside-in plus 2 inside-out, or 3 outside-in plus 1 inside-out. FlightTracker, Foxlin at 7  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.

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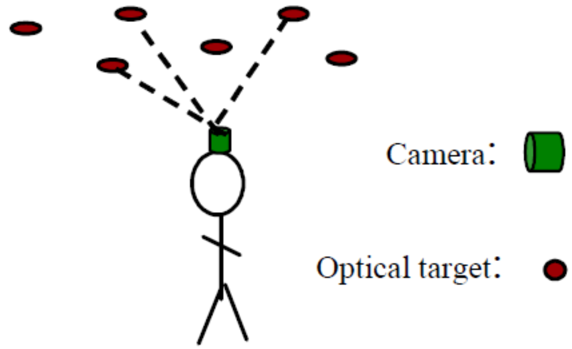
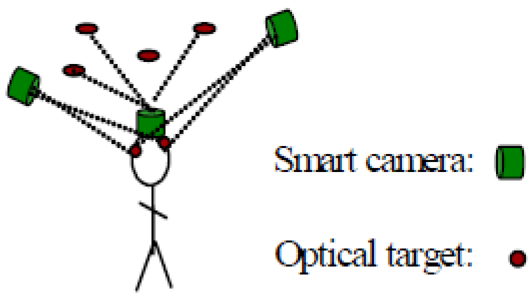
CLAIM 1	FlightTracker, Foxlin
	 **Figure 5: Inside-out optical tracking** FlightTracker, Foxlin at Fig. 5.  **Figure 6: Inside-outside-in optical tracker.** FlightTracker, Foxlin at Fig. 6 *See also* Defendants' Invalidity Contentions for further discussion.
[1.e] receiving pitch information from a sensor on the object,	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, receiving pitch information from a sensor on the object. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art.

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CLAIM 1	FlightTracker, Foxlin
	See, e.g.: In 1990, the University of North Carolina – Chapel Hill reported an optical ceiling tracker technology that can achieve milliradian angular accuracy [9]. **This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras.** Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive. Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, **InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance** [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. **To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product**. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker. This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages.

CLAIM 1	FlightTracker, Foxlin
	The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. The "inside-outside-in" configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm. Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with fewer targets or sensors. **Orientation tracking is left to the single head-mounted sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian.** FlightTracker, Foxlin at 6 **The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6. **A simulation was provided showing the improvement in an AR scenario in which pose data from an outside-in optical tracker (Northern Digital Optotrak) was combined with pose data obtained by solving a pose recovery algorithm from an inside-out camera viewing 5 LED targets. This method works by first computing the 6-DOF pose from the outside-in tracker and the 6-DOF pose from the inside-out tracker and then fusing the two 6-DOF pose estimates**. While this suffices to demonstrate the accuracy improvement that can be obtained by the inside-outside-in method, it does not reap the full benefit in robustness that can be obtained,

CLAIM 1	FlightTracker, Foxlin
	since both trackers must see enough targets to provide 6-DOF pose estimates. **In our implementation, the system will automatically fuse any 2-D bearing measurements obtained from any of the outside-in cameras and any inside-out 2-D bearing measurements with the pose being maintained by the inertial sensors, using a real-time Extended Kalman Filter. Therefore, it is not necessary for the inside-out camera to see a complete set of targets in order to provide useful data, nor is it necessary for any head-mounted target to be seen by more than one outside-in camera in order for its measurement to be used. We can block all the inside-out targets, or all the outside-in targets, or most of both sets of targets, and only slightly affect the tracking quality.** FlightTracker, Foxlin at 6-7. For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out. FlightTracker, Foxlin at 7.

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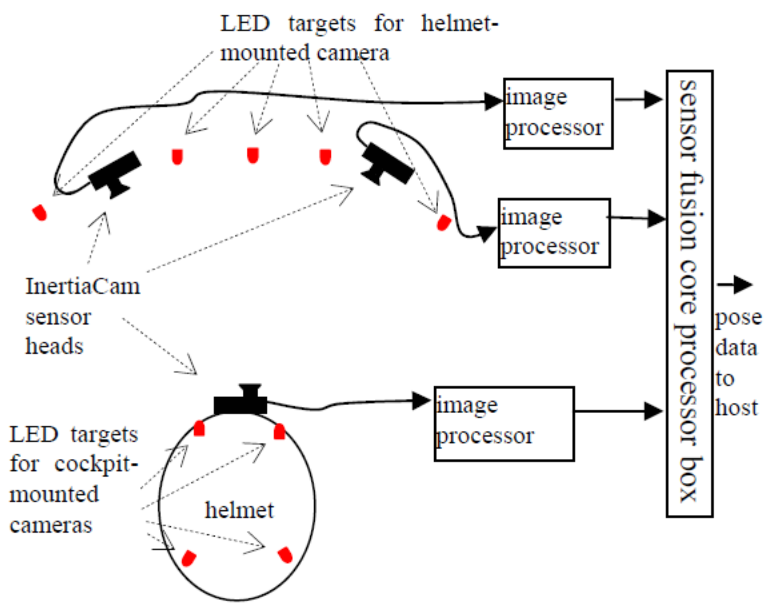
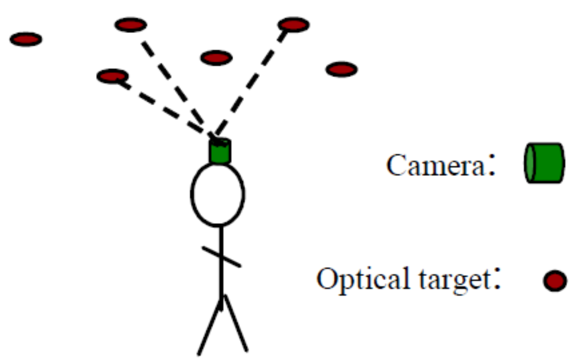
CLAIM 1	FlightTracker, Foxlin
	 **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7.  **Figure 5: Inside-out optical tracking** FlightTracker, Foxlin at Fig. 5.

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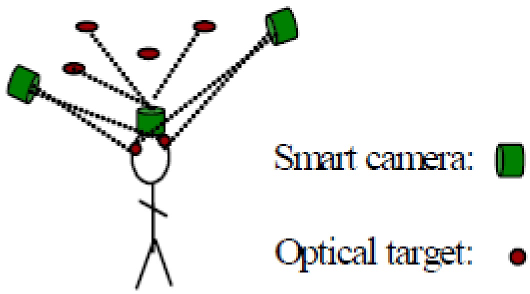
CLAIM 1	FlightTracker, Foxlin
	 Figure 6: Inside-outside-in optical tracker. FlightTracker, Foxlin at Fig. 6 *See also* Defendants' Invalidity Contentions for further discussion.
[1.f] using the coordinate information and the pitch information to obtain candidate values for the azimuth of the object,	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, using the coordinate information and the pitch information to obtain candidate values for the azimuth of the object. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art. *See, e.g.*: After decades of evolution, magnetic trackers are the most mature technology, and have been used in many cockpit helmet-tracking programs. They have the advantages of a small head-mounted sensor and no line-of-sight requirement between source and sensor. One limitation is the very short range of magnetic fields. Since the dipole fields generated by the source fall off with the cube of distance, the resolution of the tracking system falls off with the fourth power of distance [4], limiting the high-performance tracking volume to a sphere of about 30 cm surrounding the source. This may not be a problem for tracking a single helmet in a small head-motion box, but sensitivity to distortion caused by metallic objects is very much an issue in the cockpit. Elaborate mapping procedures exist to compensate for these distortions, but they are time-consuming, and must be repeated after a change as small as adjusting the pilot's seat position. A tracking technology is strongly desired which will eliminate the need for cockpit mapping. FlightTracker, Foxlin at 2.

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CLAIM 1	FlightTracker, Foxlin
	In 1990, the University of North Carolina – Chapel Hill reported an **optical ceiling tracker technology that can achieve milliradian angular accuracy** [9]. **This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras**. Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive. **Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance** [11]. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker. This configuration involves some significant performance trade-offs when choosing the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in

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CLAIM 1	FlightTracker, Foxlin
	mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. The “inside-outside-in” configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm. Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with fewer targets or sensors. Orientation tracking is left to the single head-mounted sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. **With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian.** FlightTracker, Foxlin at 6 The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. **Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6. The drawing shows two outside-in cameras, as this is enough to completely constrain the head position without any use of the inside-out camera. In concert with the inside-out camera, even one outside-in camera would be sufficient to lock up all DOFs except for translation along the outside camera’s axis. Thus two outside cameras is already highly redundant, allowing great robustness for occlusions. FlightTracker, Foxlin at 6. A simulation was provided showing the improvement in an AR scenario in which pose data from an outside-in optical tracker (Northern Digital Optotrak) was combined with pose data obtained by solving a pose recovery

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CLAIM 1	FlightTracker, Foxlin
	algorithm from an inside-out camera viewing 5 LED targets. This method works by first computing the 6-DOF pose from the outside-in tracker and the 6-DOF pose from the inside-out tracker and then fusing the two 6-DOF pose estimates. While this suffices to demonstrate the accuracy improvement that can be obtained by the inside-outside-in method, it does not reap the full benefit in robustness that can be obtained, since both trackers must see enough targets to provide 6-DOF pose estimates. **In our implementation, the system will automatically fuse any 2-D bearing measurements obtained from any of the outside-in cameras and any inside-out 2-D bearing measurements with the pose being maintained by the inertial sensors, using a real-time Extended Kalman Filter. Therefore, it is not necessary for the inside-out camera to see a complete set of targets in order to provide useful data, nor is it necessary for any head-mounted target to be seen by more than one outside-in camera in order for its measurement to be used. We can block all the inside-out targets, or all the outside-in targets, or most of both sets of targets, and only slightly affect the tracking quality.** FlightTracker, Foxlin at 6-7 For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out. FlightTracker, Foxlin at 7.

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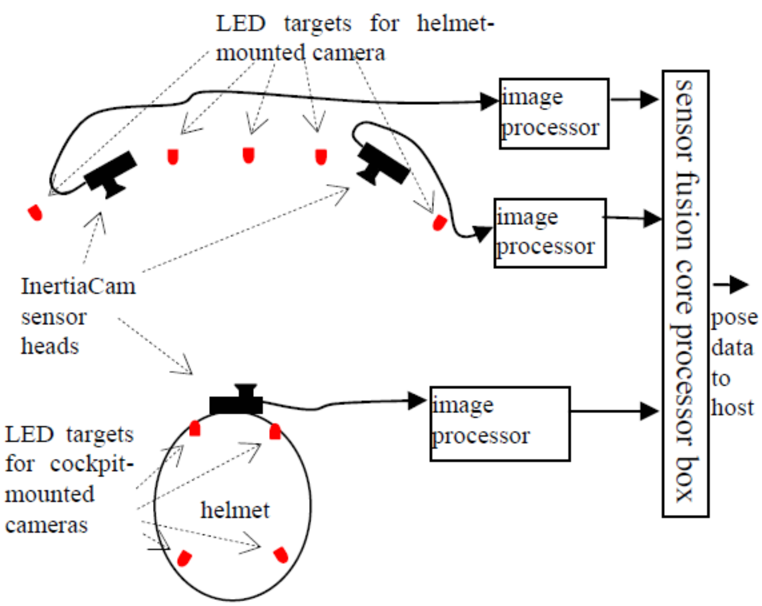
CLAIM 1	FlightTracker, Foxlin
	 **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7. During operation in the aircraft, the system starts out in acquisition mode, and then switches to tracking mode as soon as it is able to acquire an initial pose estimate. In the unlikely event that the tracking gets lost (e.g. the helmet is removed from the tracking area for an extended time), the system will automatically return to acquisition mode and re-acquire, typically in less than a second. During acquisition, the SFC scheduler requests each sensor to perform a "scan" and report all targets it can see and decode. The sensor/target measurement results are stacked in an accumulator, and if there is a sufficient combination the system solves for pose, otherwise it restarts the scan. FlightTracker, Foxlin at 7. During tracking mode, t**he system performs one scheduling operation, one inertial update and Kalman propagation step, and one Kalman measurement update (if there is a new measurement return available) on each cycle,** running at 180 cycles/second. Because of the total generality of the SFC architecture, the scheduler is actually the most complex and computationally intensive part. For each sensor, the system finds all potential targets which are currently within its field-of-view and oriented so as to be usable. The list of all potential sensor-

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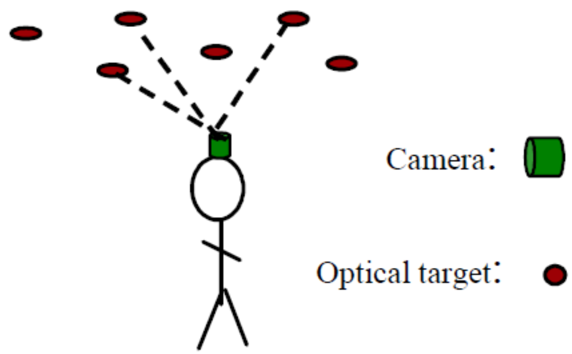
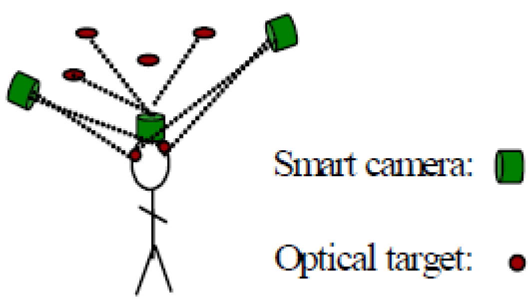
CLAIM 1	FlightTracker, Foxlin
	target pairs is submitted to an arbitration server to coordinate use of shared sensor/target resources between multiple SFCs on the same system or operating in the same area. FlightTracker, Foxlin at 8.  **Figure 5: Inside-out optical tracking** FlightTracker, Foxlin at Fig. 5.  **Figure 6: Inside-outside-in optical tracker.** FlightTracker, Foxlin at Fig. 6.

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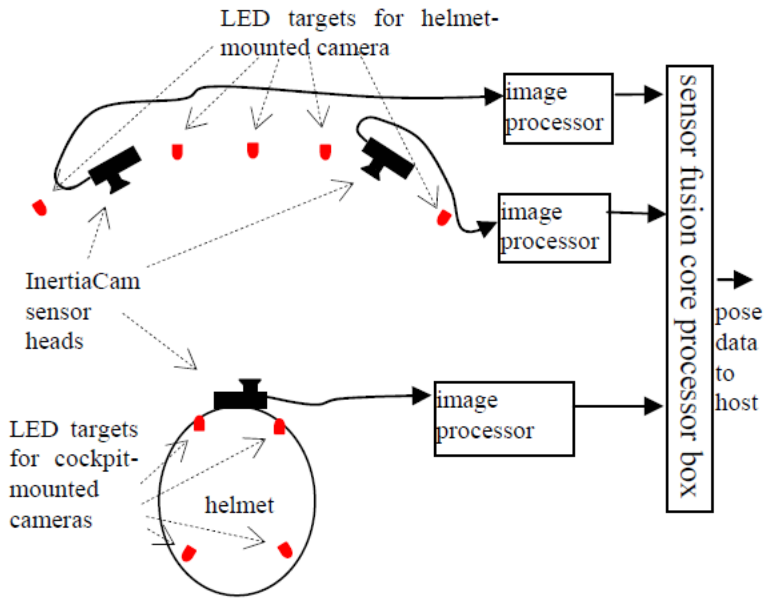
CLAIM 1	FlightTracker, Foxlin
	 **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7. *See also* Defendants' Invalidity Contentions for further discussion.
[1.g] selecting one azimuth value based on an evaluation of the candidate azimuth values in equations relating the coordinate information and pitch information to distances of the points from the camera.	At least under Plaintiffs' apparent infringement theory, FlightTracker, Foxlin discloses, either expressly or inherently, selecting one azimuth value based on an evaluation of the candidate azimuth values in equations relating the coordinate information and pitch information to distances of the points from the camera. In the alternative, this element would be obvious over FlightTracker, Foxlin in light of the other references disclosed in Defendants' Invalidity Contentions and/or the knowledge of one of ordinary skill in the art. *See, e.g.*: After decades of evolution, magnetic trackers are the most mature technology, and have been used in many cockpit helmet-tracking programs. They have the advantages of a small head-mounted sensor and no line-of-sight requirement between source and sensor. One limitation is the very short range of magnetic fields. Since the dipole fields generated by the source fall off with the cube of distance, the resolution of the tracking system falls off with

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	the fourth power of distance [4], limiting the high-performance tracking volume to a sphere of about 30 cm surrounding the source. This may not be a problem for tracking a single helmet in a small head-motion box, but sensitivity to distortion caused by metallic objects is very much an issue in the cockpit. Elaborate mapping procedures exist to compensate for these distortions, but they are time-consuming, and must be repeated after a change as small as adjusting the pilot's seat position. A tracking technology is strongly desired which will eliminate the need for cockpit mapping. FlightTracker, Foxlin at 2. In 1990, the University of North Carolina – Chapel Hill reported an **optical ceiling tracker technology that can achieve milliradian angular accuracy [9].** This was accomplished by the use of "inside-out" optical tracking, in which the cameras are placed on the user's head and the targets fixed on the ceiling. This arrangement provides very high sensitivity to head rotations because even a small rotation will cause the LEDs on the ceiling to move substantially in the image plane of the cameras. Unfortunately, to also resolve position well requires use of multiple cameras aimed in different directions. The "HiBall" sensor cluster consists of a dodecahedral assembly of 6 lenses and 6 lateral-effect photo-diodes (LEPD), producing effectively 26 narrow fields of view [10]. This system was designed to provide high accuracy over a large area in a laboratory environment, but is not well suited for use in simulator environments or cockpits because 1) it requires a very dense array of bright IR LEDs as its targets, 2) reflective surfaces such as the canopy or screens in a simulator could cause significant errors if they create any reflection of an activated LED in one of the fields-of-view, and 3) the weight is prohibitive. **Considering the wisdom of the inside-out optical approach for applications requiring high angular precision and the limitations of the HiBall implementation, InterSense developed a new optical/inertial tracking technology to target mobile robot navigation and wearable augmented reality systems for large scale manufacturing, construction and aircraft maintenance [11]**. The first prototype vision-inertial self-tracker (VISTracker) was demonstrated at ISAR 2001. Since then, we have made many improvements in system architecture, hardware and software implementation. The VIS-Tracker system has now been demonstrated at numerous conferences and is now in beta-testing at several customer sites. To the best of our knowledge, the VIS-Tracker is the first hybrid optical/inertial tracking product. FlightTracker, Foxlin at 5. Figure 4, Figure 5, and Figure 6 show three optical tracking configurations that can be created almost automatically using our flexible sensor fusion architecture [12]. Figure 5 shows an inside-out optical tracker using just one camera, like the VIS-Tracker. This configuration involves some significant performance trade-offs when choosing

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	the field-of-view (FOV) of the lens. The geometric dilution of precision (GDOP) is a function describing the sensitivity of a tracking pose recovery algorithm (PRA) to small errors in the input measurements. The optimal GDOP in this configuration occurs when using three fiducials so widely separated that the lines of sight (doted lines in the figure) are all nearly orthogonal. To be able to select such widely separated fiducials in every frame requires using a very wide-angle lens, over 100° FOV. However, such a wide-angle lens has some disadvantages. The distortion in the edges becomes so extreme that it cannot be completely compensated. A measurement error of 0.2 pixels r.m.s. in determination of the centroid of a fiducial corresponds to a larger angular measurement error in mRads, since each pixel spans a larger angle. And the fiducials must be made larger to be readable at the same distance. On the other hand, a narrower lens can use smaller fiducials, but they need to be more densely spaced to make sure there are always several in view. Thus, practical lens choices for single-camera self-tracking range from about 60-90°. Since this is on the narrower side of the ideal GDOP, the position stability suffers, especially in the depth axis, while the angular stability is only affected a little bit, as a result of the lateral errors in position determination. FlightTracker, Foxlin at 5-6. The "inside-outside-in" configuration in Figure 6 offers excellent orientation and position tracking without requiring unduly high-resolution sensors, large stand-offs or large numbers of sensors. The outside-in sensors need just one head-mounted target visible to determine position to under 1 mm. Keeping one target visible for all head poses is much easier than guaranteeing visibility of three targets at all times, resulting in greater robustness with fewer targets or sensors. Orientation tracking is left to the single head-mounted sensor, which intrinsically offers extremely high angular resolution even with a modest resolution sensor. **With the position already constrained by the outside sensors, there is no need to insure that the head-mounted sensor can see several widely spaced targets. In fact, it only needs to see one target to fully constrain the azimuth and elevation angles with a precision equal to the angular resolution of the camera, a fraction of a milliradian.** FlightTracker, Foxlin at 6 **The roll, which is less critical for display registration, will be determined to sufficient accuracy by gravity, and to even higher accuracy if the head mounted camera can see two targets in the cockpit or if the outside-in cameras can see two targets on the helmet. Therefore, one can select almost any FOV for the inside-out camera and still obtain outstanding performance in all 6 degrees of freedom.** FlightTracker, Foxlin at 6.

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	The drawing shows two outside-in cameras, as this is enough to completely constrain the head position without any use of the inside-out camera. In concert with the inside-out camera, even one outside-in camera would be sufficient to lock up all DOFs except for translation along the outside camera's axis. Thus two outside cameras is already highly redundant, allowing great robustness for occlusions. FlightTracker, Foxlin at 6. A simulation was provided showing the improvement in an AR scenario in which pose data from an outside-in optical tracker (Northern Digital Optotrak) was combined with pose data obtained by solving a pose recovery algorithm from an inside-out camera viewing 5 LED targets. **This method works by first computing the 6-DOF pose from the outside-in tracker and the 6-DOF pose from the inside-out tracker and then fusing the two 6-DOF pose estimates. While this suffices to demonstrate the accuracy improvement that can be obtained by the inside-outside-in method, it does not reap the full benefit in robustness that can be obtained, since both trackers must see enough targets to provide 6-DOF pose estimates. In our implementation, the system will automatically fuse any 2-D bearing measurements obtained from any of the outside-in cameras and any inside-out 2-D bearing measurements with the pose being maintained by the inertial sensors, using a real-time Extended Kalman Filter.** Therefore, it is not necessary for the inside-out camera to see a complete set of targets in order to provide useful data, nor is it necessary for any head-mounted target to be seen by more than one outside-in camera in order for its measurement to be used. We can block all the inside-out targets, or all the outside-in targets, or most of both sets of targets, and only slightly affect the tracking quality. FlightTracker, Foxlin at 6-7 For the VIS-Tracker, the DSP was programmed to automatically detect and decode circular fiducial patterns. Fiducial patterns or even natural features in the environment are desirable optical targets for a wearable self-tracker which needs to operate over an area too large to install active targets throughout. However, in the cockpit, active targets such as LEDs are practical, take up less space than patterns, and offer more robust detection under cockpit lighting conditions. We have modified the firmware in the InertiaCam to decode and track LEDs instead of fiducials. To automatically acquire initial pose, the system needs to identify individual LED targets and look up their pre-stored positions. We have invented a novel scheme of modulating the LEDs with ID codes, which requires no synchronization between the LEDs or the cameras, and can be decoded simply in the InertiaCam firmware during acquisition. The Sensor Fusion Core (SFC) firmware based on the architecture of [12] was implemented using the Mathworks' Real-Time Workshop with a custom-developed target for the ETS real-time operating system, running in an embedded x86 processor box. During initialization, the SFC invokes the meta-driver to enumerate all the sensor and target hardware attached to the system, and then reads configuration files (or

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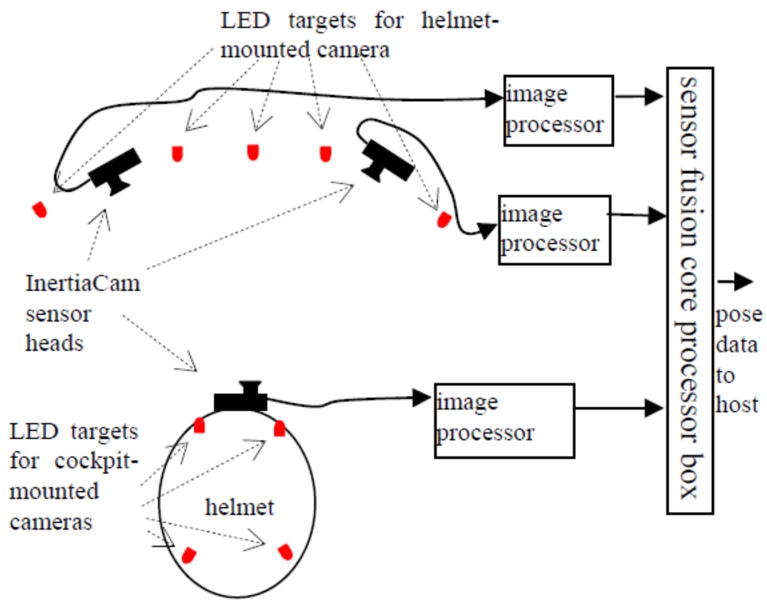
	solicits user input if necessary) to determine which cameras are used inside-out and which are used outside-in. The system will support an arbitrary number of cameras in each role, although if there are less than two outside-in cameras, there must be at least one inside-out. FlightTracker, Foxlin at 7.  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7. During operation in the aircraft, the system starts out in acquisition mode, and then switches to tracking mode as soon as it is able to acquire an initial pose estimate. In the unlikely event that the tracking gets lost (e.g. the helmet is removed from the tracking area for an extended time), the system will automatically return to acquisition mode and re-acquire, typically in less than a second. During acquisition, the SFC scheduler requests each sensor to perform a "scan" and report all targets it can see and decode. The sensor/target measurement results are stacked in an accumulator, and if there is a sufficient combination the system solves for pose, otherwise it restarts the scan. FlightTracker, Foxlin at 7.

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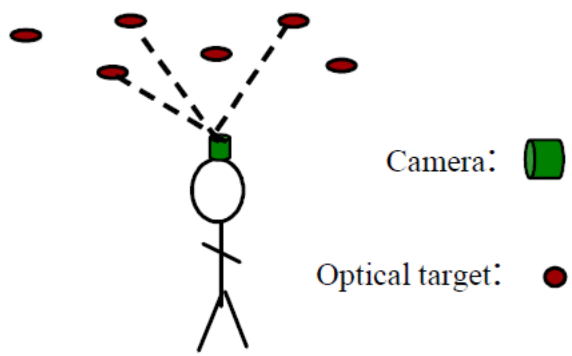
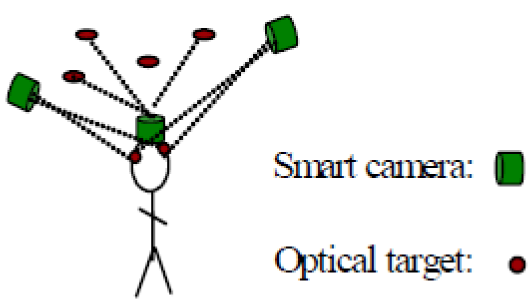
	During tracking mode, **the system performs one scheduling operation, one inertial update and Kalman propagation step, and one Kalman measurement update (if there is a new measurement return available) on each cycle, running at 180 cycles/second.** Because of the total generality of the SFC architecture, the scheduler is actually the most complex and computationally intensive part. For each sensor, the system finds all potential targets which are currently within its field-of-view and oriented so as to be usable. The list of all potential sensor-target pairs is submitted to an arbitration server to coordinate use of shared sensor/target resources between multiple SFCs on the same system or operating in the same area. FlightTracker, Foxlin at 8.  **Figure 5: Inside-out optical tracking** FlightTracker, Foxlin at Fig. 5.  **Figure 6: Inside-outside-in optical tracker.**

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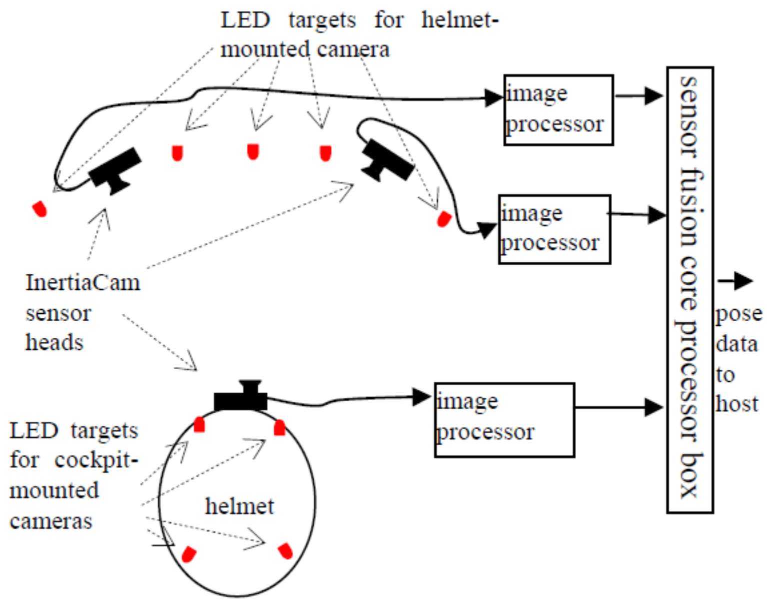
	FlightTracker, Foxlin at Fig. 6  **Figure 7: Schematic overview of tested system configuration** FlightTracker, Foxlin at Fig. 7. *See also* Defendants' Invalidity Contentions for further discussion.